6 - 42 Status Report of On-line Ion Sources in 2014

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In 2014, the service time of the two on-line ion sources of HIRFL-CSR accelerator facility, SECRAL and LECR3 is 3 594 and 3 457.2 h, respectively, amouting to 7051.2 h. 17 kinds of ion beams have been delivered successfull. The failure time is shrinked down to 8 h in this year, which is the lowest among these years. Table 1 summarizes the main information about the ion beams delievered by the two ion sources. Fig. 1 shows the comparison of the ion beam delivering time for HIRFL-CSR accelerator facitily from the three ion sources, LECR3, SECRAL and LAPECR1 since 2007.

Table 1 Ion beams delivered by SECRAL and LECR3 to HIRFL accelerator in 2014.

Equipment	Ion beam	Extraction HV/kV	Ion beam intensit/eμA	Service time/h
SECRAL	$^{36}Ar^{15+}$	22.36	60	206
	$^{40}Ar^{12+}$	19.24/23.58	130	367
	$^{58}Ni^{19+}$	21.60/21.95	20	1512.5
	$^{78}Kr^{19+}$	18.59	120	667
	$^{86}Kr^{17+}$	18.89	100	371.5
	$^{209}Bi^{31+}$	10.25	30	470
LECR3	H_2^+	22.82	500	296.5
	$^{12}C^{3+}$	18.54	150	132
	$^{12}C^{4+}$	16.23/23.07	200	926
	$^{14}N^{5+}$	17.37	160	97.5
	$^{16}O^{6+}$	20.50/21.96	200	825
	$^{18}O^{6+}$	23.07	200	222.5
	$^{20}Ne^{7+}$	19.38	100	218.5
	$^{22}Ne^{8+}$	22.64	60	126
	$^{32}S^{9+}$	15.31	50	168
	$^{40}Ar^{9+}$	19.78	66	175
	$^{40}Ca^{12+}$	18.37/18.73	25～40	270.2

The two on-line ion sources are operated for different goals. LECR3 is mainly used to provide the ion beams with low medium charge states, such as C^{4+}, Ar^{8+}, Ca^{12+}, *etc.*, while SECRAL aims to produce intense highly charged ion beams, especially metallic ones, such like Ni^{19+}, Bi^{31+}, U^{33+}, and so on. The operation time of the two ion sources for producing metallic ion beams accounts for 32% of the total operation time. The ion beam intensities delivered by the ion sources meet the requirements of the most experiments. In addition, SECRAL was also operated for machine study this year.

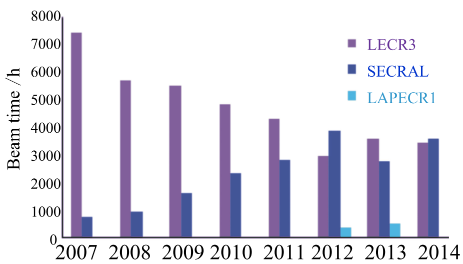

Fig. 1 (color online) Beam delivering time of the three on-line ion sources from 2007 to 2014.

Fig. 2 (color online) The old and new injection components of SECRAL.

At the beginning of 2014, SECRAL was upgraded with a new injection component, as shown in Fig. 2. The most significant modification compared with the old version is that one of the channels for ovens was modified to accommodate the sputtering component. Another improvement is the new one which gives the possibility to adjust the positions of the biased voltage plate and sputtering component in the range of 0 to 50 mm axially. Nearly all techniques in ECR ion sources, such as oven, sputtering component, negatively biased voltage, gas feeding, double RF frequency heating (18+24 GHz), are integrated into the new injection component, which shortened time for beam shifts to a great extent. The good performance of SECRAL in this year indicates that the modification is successful.

Several kinds of metallic ion beams have been produced by SECRAL in 2014. A low-temperature oven made of molybdenum was used to produce bismuth beams. With double frequency heating (24+18 GHz), 720 eμA of Bi^{30+}, 220 eμA of Bi^{36+}, 100 eμA of Bi^{41+} and 5.4 eμA of Bi^{54+} have been produced. It turns out that it is more benefit for the production of metallic ions to put the oven close to the plasma due to the extra heating induced by plasma. In this situation the electrical power loaded on the oven lowered. The material consumption decreased from 5.0 to 0.31 mg/h. Fig. 3 gives a high charge state spectrum of Bi optimized for Bi^{41+}.

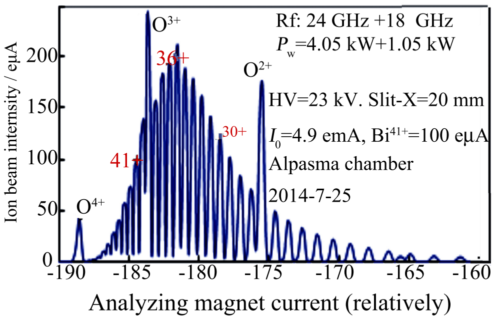

Fig. 3 (color online) CSD spectrum to optimize $^{209}Bi^{41+}$. CSD spectrum of Bi ion beams obtained when the ion source was optimized for Bi^{41+} with double-frequency heating (24 GHz/ 4.0 kW+18 GHz/ 1.0 kW)

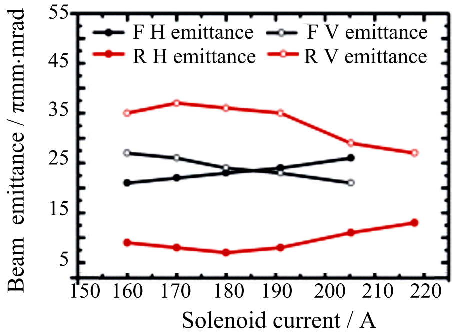

Fig. 4 (color online) Measured beam emittances by changing the focusing strength and reversing the polarity of the beam line solenoid. ("H" means horizontal, "V" means vertical, "F" means forward current being loaded on the solenoid, "R" means the polarity of the solenoid lens is reversed.)

The production of calcium beam was also realized with a low-temperature oven and double frequency heating. At the RF power of 2.4+0.7 kW and extraction voltage of 20 kV, 660 eμA of 40 Ca^{12+} was obtained.

For the production of uranium beams, the ion source was tested with paraxial sputtering. The sputtering current was decreased to 5.0 mA, while only 100 eμA of $^{238}U^{33+}$ was obtained, which is quite lower compared with 202 eμA achieved with the sputtering component at the axis in 2013.

Tantalum beams was also produced with sputtering method. 32 eμA of Ta^{27+} was produced with 1.0 kW power of 18 GHz, and the beam was quite stable. This beam is expected for the experiments on single event effect.

Gold beams are required by the future experiments, so SECRAL was operated with a universal oven to produce Au beams. At the RF power of 1.0 kW, stable Au^{31+} beam of 52 eμA was obtained, which can meet the requirements of the experiments.

Fig. 5 (color online) The 28 GHz microwave Generator.

Among metallic ion beams, the results on iron beams was unsatisfied. The temperature of the universal oven was limited at around 1 400 °C. Only 18 eμA of Fe^{18+} was obtained. Another reason for low intensity of Fe beam was the ion source contaminated with argon. The intensity of Fe beam could not meet requirements of the experiment, so more efforts are needed for the production of Fe beams.

In order to study the LEBT of SECRAL, two experiments were carried out. One was to investigate the Q/A selector system and the other was to study the transverse coupling property of the beam. The results of the first experiment show that, for high-intensity ion beams, increasing the initial focusing strength of the solenoid is beneficial to avoid the large-radius aberration in the analyzing magnet and improve the beam quality but with the sacrifice of the momentum resolution of the system due to the space charge effect. In the second experiment it is found that the projection emittances on xx' and yy' planes transfer from one direction to the other as the focusing strength of the beam line solenoid is increased. Meanwhile, the emittances have a completely different allocation in the two orthogonal directions on the cross section of the beam while reversing the magnetic polarity of the solenoid lens, as shown in Fig. 4. This phenomenon indicates that the ion beams extracted from the ECR ion source are transversely coupled.

Preliminary experiments of afterglow mode were conducted with SECRAL. Pulsed ion beams have been obtained with AG mode, while more research is needed to enhance the beam intensity.

A new 28 GHz RF generator has been installed in position, as shown in Fig. 5. SECRAL will be operated with the combination of 28+24 GHz RF power to produce metallic ion beams in 2015.